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**REMARKS**

The present invention is a method for forming a module providing real-time simulation of a flow mode, at any point of a pipe, of a multiphase fluid stream comprising at least a liquid phase and at least a gas phase, for imposed operating conditions concerning determined structural parameters relative to the pipe, and a set of determined physical quantities, with fixed variation ranges for the parameters and the physical quantities, by a modelling system based on non-linear neural networks having inputs for the structural parameters and the physical quantities, outputs where quantities necessary for estimation of the flow mode are available, and at least one intermediate layer. The method determines the non-linear neural networks so as to adjust to values of a learning base with predetermined tables connecting values outputted from output data for the output to corresponding values of input data to the inputs and wherein the learning base is suited to the imposed operating conditions. See page 4, lines 11-13, which refer to "a learning base suited to the imposed operating conditions" which is the subject matter now recited in claim 1 as amended. Moreover, see page 8, lines 13-15 and 20-23.

Claims 1-4 stand rejected under 35 U.S.C. §102 as being anticipated by United States Patent 5,649,064 (Jorgensen et al). With respect to claim 1, the Examiner reasons as follows:

As per claim 1, Jorgensen discloses a system and method for modeling flow activities in a dynamic system such as hydrodynamic system with feature limitations very identical to the claimed invention. According to Jorgensen, the simulation method includes steps of determining the neural network so as to adjust to values of a learning base with predetermined tables connecting values obtained for output data from the output to corresponding values of input data to the inputs and wherein the learning base imposed operating conditions and the determined neural networks

are adjusted to the imposed operating conditions (Figs, 4-6, col. 2, lines 49-57, col. 4, lines 7-20, cols. 5-9, for exemplary).

This ground of rejection is traversed for the following reasons.

Jorgensen discloses a system and method for modelling the flow performance features of an object using a single phase fluid (air) in a preferred environment of a wind tunnel. While Jorgensen does disclose a neural network having an input layer, a hidden layer and an output layer, such network is disclosed in the context of modelling an object in a wind tunnel from performance data on the object. See the Abstract and the discussion of the neural network of Fig. 5.

Substantial differences exist between the claimed invention and the subject matter of Jorgensen et al. It is noted that the Examiner has apparently not given any weight to the totality of the limitations expressed in claim 1 which includes the preamble which is incorporated by reference in the body of claim 1. The claimed method recites determining the "non-linear neural networks" which have antecedent basis in the preamble. The preamble of claim 1 also recites "forming a module providing real-time simulation of a flow mode, at any point of a pipe, a multiphase fluid stream comprising at least a liquid phase and at least a gas phase, for imposed operating conditions concerning determined structural parameters relative to the pipe, and a set of determined physical quantities with fixed variation ranges for the parameters and the physical quantities by a modelling system based on a non-linear neural networks each having inputs for the structural parameters and the physical quantities, outputs where quantities necessary for estimation of the flow mode are available in at least one

intermediate layer" which also is referred to in the method step of claim 1 which states "wherein the learning base is suited to the imposed operating conditions". Incorporation by reference of the preamble of claim 1 into the method recited in the body of claim 1 makes the preamble of claim 1 limiting. The disclosure of Jorgensen et al is not relevant to patentability of claim 1 when the preamble is considered as limiting the claimed method steps.

Moreover, the "imposed operating conditions" have no counterpart in Jorgensen et al. Figs. 4-6 in column 2, lines 49-57 and column 4, lines 7-29 and columns 5-9, which have been cited by the Examiner, do not disclose anything pertaining to the aforementioned subject matter.

Jorgensen et al discloses a neural network utilized for modelling of the single phase fluid stream with a preferred application being utilized in a wind tunnel which differs from the claimed liquid and gas phases.

Moreover, the steps of claim 1 differ substantially from Jorgensen et al in reciting "determining the non-linear neural networks so as to adjust to values of a learning base with predetermined tables connecting values obtained for output data from the output to corresponding values of input data to the inputs and wherein the learning base is suited to the imposed operating conditions and the determined neural networks are adjusted to the imposed operating conditions". As stated above, the preamble limits the claimed method which involves the imposed operating conditions which, as recited in the preamble, concern predetermined structural parameters relative to the pipe and a set of determined physical quantities, with fixed variation ranges for the parameters in the physical quantities, by a modelling system based on non-linear neural networks each having inputs for the structural parameters and physical quantities, outputs where

quantities necessary for estimation of the flow mode are available in at least one intermediate layer". It is submitted that Jorgensen et al do not disclose the aforementioned imposed operating conditions as recited in the preamble and method of claim 1.

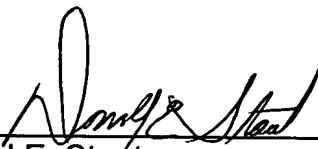
Claim 1 has been amended to refer in the preamble to "for imposed operating conditions" and furthermore, the learning base in the body of claim 1 has been recited as "is suited to the imposed operation conditions". The specification has literal support for claiming of the learning base being suited to the imposed operation conditions in the places noted above at the last part of the first paragraph of the Remarks.

In view of the foregoing amendments and remarks, it is submitted that each of the claims in the application is in condition for allowance. Accordingly, early allowance thereof is respectfully requested.

To the extent necessary, Applicants petition for an extension of time under 37 C.F.R. §1.136. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account No. 01-2135 (612.40914X00) and please credit any excess fees to such Deposit Account.

Respectfully submitted,

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Attachments

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SECOND SUBSTITUTE SPECIFICATON

PATENT

INSTITUT FRANÇAIS DU PETROLE

**METHOD FOR FORMING AN OPTIMIZED NEURAL NETWORK MODULE  
INTENDED TO SIMULATE THE FLOW MODE OF A MULTIPHASE  
FLUID STREAM**

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ABSTRACT

A method for forming a module (hydrodynamic or thermodynamic for example) intended for real-time simulation of the flow mode, at any point of a pipe, of a multiphase fluid stream comprising at least a liquid phase and at least a gas phase. The method comprises using a modelling system based on non-linear neural networks each having inputs for structure parameters and physical quantities, outputs where quantities necessary for estimation of the flow mode are available, and at least one intermediate layer. The neural networks are determined iteratively to adjust to the values of a learning base with predetermined tables connecting various values obtained for the output data to the corresponding values of the input data. A learning base suited to the imposed operating conditions is used and optimized neural networks best adjusted to the imposed operating conditions are generated.



## BACKGROUND OF THE INVENTION

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### Field Of The Invention

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**[0001]** The present invention relates to a method for forming a neural network module for real-time simulation of the flow mode, at any point of a pipe, of a multiphase fluid stream comprising at least a liquid phase and at least a gas phase, that is best suited to operating conditions and to a set of fixed physical quantities.

### Description of the Prior Art

**[0002]** Transporting hydrocarbons from production sites to treating plants constitutes an important link in the petroleum chain. It is a delicate link because of the complex interactions between the phases forming the transported effluents. The basic objective for operators is to reach an optimum productivity under the best safety conditions. They therefore have to control as best they can the velocity and the temperature of the transported hydrocarbons so as to avoid unnecessary pressure drops, unwanted deposits and unsteady-state flows. The method that is generally used ~~consists in modelling models~~ in the best possible way the transportation of complex multiphase streams so as to provide at all times an image of the flows in the various parts of the production chain, taking into account the precise constitution of the effluent, the flow rates, the pressures and the flow modes.

**[0003]** There are currently various software modules for simulating the transport of complex multiphase streams, allowing to ~~design~~ designing of suitable production equipments at an early stage.

**[0004]** U.S. Patents 5,550,761, 6,028,992 and ~~US~~-5,960,187 filed by the assignee notably describe modelling modules forming the TACITE model known in the art, allowing simulation of the transport of complex multiphase streams as a steady or transient flow and ~~accounts~~ accounting for instability phenomena that occur because of the irregular geometry of the formation crossed by the pipe or of the topography thereof, referred to by specialists as "terrain slugging" or "severe slugging".

**[0005]** The simulation modules are as complex as the modelled phenomena. Precision and performances can only be obtained after a relatively long modelling time, which is not really compatible with real-time management. That is the reason why these modelling modules cannot be used as they are for real-time management of the production. It therefore appears necessary to use modelling methods offering a good compromise between calculating speed and accuracy of results.

**[0006]** French Patent application 00/09,889 filed by the assignee describes a method of real-time estimation of the flow mode, at any point of a pipe having a structure that can be defined by a certain number of ~~structure~~ structural parameters, of a multiphase fluid stream defined by several physical quantities and comprising liquid and gas phases. According to this method, the flow mode is modelled :

- by forming a non-linear neural network with an input layer having as many inputs as there are ~~structure~~structural parameters and physical quantities necessary for good estimation of the output, an output layer with as many outputs as there are quantities necessary for estimation of the flow mode, and at least one intermediate layer,

- by forming a learning base with predetermined tables connecting various values obtained for the output data to the corresponding values of the input data, and

- by determining, by iterations, weighting factors of the activation function allowing proper connection of the values in the input and output data tables.

**[0007]** Output data of the neural network is preferably analyzed so as to sort, among the values of the output data of the neural network, only the pertinent data to be taken into account for iterative determination of the weighting coefficients of the activation function.

## SUMMARY OF THE INVENTION

**[0008]** The method according to the invention forms a module (hydrodynamic or thermodynamic for example) which provides real-time simulation of the flow mode, at any point of a pipe, of a multiphase fluid stream comprising at least a liquid phase and at least a gas phase, so that it is best suited to fixed operating conditions concerning a certain number of determined



~~structure-structural~~ and physical parameters relative to the pipe, and a set of determined physical quantities (hydrodynamic or thermodynamic quantities for example), with fixed variation ranges for the parameters and the physical quantities.

**[0009]** The method of the invention comprises using a modelling system based on non-linear neural networks each having inputs for ~~structure-structural~~ parameters and physical quantities, outputs where quantities necessary for estimation of the flow mode are available, and at least one intermediate layer. The neural networks are determined iteratively so as to adjust to the values of a learning base with predetermined tables connecting various values obtained for the output data to the corresponding values of the input data.

**[0010]** The method forms a learning base suited to the imposed operating conditions and optimized neural networks best adjusted to the imposed operating conditions are generated.

**[0011]** In the case, for example, where the module is to be integrated in a general multiphase flow simulation model, both hydrodynamic and thermodynamic, the model is used to form the learning base so as to select the set of physical quantities that is best suited to the model, as well as the variation ranges fixed for the parameters and the physical quantities, and the optimized neural networks that best adjust to the learning base formed are generated.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** Fig. 1 illustrates a neural network in accordance with the invention.

**[0013]** Fig. 2 is a table expressing classification percentage obtained for three output classes of the neural network of Fig. 1.

**[0014]** Fig. 3 is a table illustrating classification results.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

### General points concerning the formation of the neural networks system

**[0015]** A circulation of multiphase fluids in a pipe with at least a liquid phase and at least a gas phase is considered in formation of a neural system providing, from a certain number of geometrical and physical input data relative to the pipe and of physical data relative to the fluids, instantaneously, for each section of the fluid stream, an estimation of the flow mode or, from a certain number of data linked with the pressure and temperature conditions of the fluid, and with the composition of the fluid, giving the thermodynamic behavior of the fluid. The whole of this input data constitutes a database.

#### 1) Input and output data

**[0016]** The input data ~~is~~are for example :

- geometrical and physical data of the pipes : diameter, roughness and angle of inclination of the pipe, and thermodynamic data : density of the gas, density of the liquid, viscosity of the gas, viscosity of the liquid, etc. ; the whole of this data constitutes an n-uplet, and

- hydrodynamic data characterizing the mixture : gas/liquid surface tension, volume fraction of gas, barycentric velocity of the mixture, etc.,

or :

- thermodynamic data relative to the environment of the fluid : pressure, temperature, the whole of this data constituting an n-uplet, as well as data characterizing the composition of the mixture : molar mass, critical properties, enthalpy coefficients, etc.

**[0017]** The model produces for example at the output the hydrodynamic behavior of the effluents, and notably the flow regime. It evaluates and delivers at two main outputs hydrodynamic data in the part of the pipe where the flow type is to be determined, the velocity difference  $dV$  between gas and liquid for example, or the stratified type flow fraction  $\beta$  ( $\beta \in [0 ; 1]$ ) (type where the liquid phase flows in the lower part of the pipe). Other quantities qualifying the flow type can be calculated from these two outputs.

**[0018]** In applications to thermodynamics, the model produces at the output the thermodynamic quantities of the effluents such as, for example, the number and the nature of the phases in presence or the molar fractions of the phases.

## 2) Structure of the system of networks

**[0019]** The function to be modelled by the hydrodynamic or thermodynamic model involves various subfunctions that can be solved by using, if necessary, several networks playing a well-determined part within the model. For example, a network can be dedicated to the non-linear function regression, while another network is dedicated to the classification of the various flow regimes. Besides,

the connections to be established between the networks or between the module and its outer environment can require complementary data processing (data normalization, denormalization, etc.). The system is therefore referred to as based on neural networks.

**[0020]** In order to connect the whole of the hydrodynamic or thermodynamic input and output data, a system of neural networks is formed, these networks being preferably of MLP type, well-known in the art since it is particularly well-suited for physical phenomena modelling. Its structure allows describing the dynamic as well as the static components of the phenomena, even by fixing, if necessary, some of its parameters at a rectified value, therefore physically representative. Thus, knowing physical equations that govern the flows allows, for example, enrichment of the network and a best adaption thereof to the physical phenomena modelled thereby.

**[0021]** The neural network comprises (Fig.1) three layers for example: the input layer of ten neurons corresponding to the ten data (mentioned above) of the complete physical model, an output layer of two neurons corresponding to the two parameters  $dV$  and  $\beta$  sought, and an intermediate layer, referred to as hidden layer, whose number of neurons  $N_c$  is optimized. The network is totally connected. The non-linearity of this network is obtained by a sigmoid activation function governing the behavior of the neurons in the hidden layer. The neurons of the output layer can be selected linear or non-linear. The activation function can be the identity function for example.

### 3) Learning

**[0022]** The weights of this structure are determined at the end of the learning stage; during this stage, the network is supplied with a set of data forming the learning base of the network, and the structure and the weights of the network are optimized by minimizing the errors observed for all the samples of the base, between the output data resulting from network calculations and the data expected at the output, given by the base. The errors can be the absolute errors between the input and output quantities or the relative errors, according to the performance desired for the network.

**[0023]** The generalization powers of the network are then tested from its capacity to properly calculate the two outputs for inputs that are unknown thereto.

#### Implementation particularities

**[0024]** The system based on neural networks modelling the hydrodynamic module or the thermodynamic module is defined by a set of parameters ~~that for~~ which the learning base allows determination and fixing thereof. These parameters are adaptable to the constraints imposed by the use to which this module is dedicated.

**[0025]** If the module is intended for a general use, the learning base has to be exhaustive, i.e. include all the available data concerning the various

inputs/outputs ; the module can thus represent all of the cases that can be encountered in the field.

**[0026]** If the module is used in a more specialized framework or context, production of an oil field for example, adjustment is carried out on a more restricted learning base containing only the data that can be encountered in this field alone : type or structure of the pipes or pipelines, topographic variations, more restricted ranges of variation of certain hydrodynamic or thermodynamic quantities, etc. The parameters of the neural networks are in this case calculated so as to obtain a product specific to a given configuration, in order to represent in the best possible way the flows in operating ranges specific to this field.

**[0027]** This module is thus adaptable to the various described uses thereof.

#### Environment of the neural network module

**[0028]** The module developed can be used alone, without associated modules. In this case, the module is adjusted to databases formed according to the desired use, according to whether the context is general or specific. It is independent and allows estimation of the hydrodynamic or thermodynamic quantities likely for monitoring of the behavior of effluent flows in pipelines, from a learning base containing physical and thermodynamic quantities data provided otherwise.

**[0029]** The module can also be implemented in any model (set of simulation software modules capable of simulating the transient and/or steady behavior of multiphase flows, such as for example the TACITE model mentioned above). In

this case, the module is adjusted to reference models representing the current state of the art, and to associated databases that widely cover the whole of the definition domain of the n-uplet formed by the input data. This adjustment thus takes into account the specificities of the software environment in which it is included.

**[0030]** To form the learning base that is best suited to the model where the neutral system is to be integrated, the model is advantageously used to connect the input and output data.

#### Examples of use

**[0031]** The module based on neural networks is suited for any application requiring hydrodynamic representation of effluents: formation of flow predictive simulation codes, real-time simulation or training simulation, etc. Active production control methods can also be based on such a module.

#### Optimization examples

**[0032]** Consider for example the case where a network giving the classification of the flow type of multiphase fluids to be ~~optimizes~~ optimized: stratified type or class C1 flow (defined above), intermittent type or class C2 flow (characterized by a succession of liquid and gaseous slugs), or dispersed type or class C3 flow (the liquid being carried along in form of fine droplets), according to inputs as described above under the heading "General Points Concerning the Formation of the Network".

**[0033]** A neural network is first formed by means of a general base. The resulting optimum structure obtained contains 30 neurons, with a single hidden layer. The network confusion-table obtained (Fig.2) expresses the classification percentage obtained in the three output classes of the network for each class of the database.

**[0034]** The database used is then restricted to particular configurations, which reduce the ranges of variation of the various inputs of the network. The optimum neural network consists in this case of 28 neurons and comprises a single hidden layer. The classification result is shown by the confusion table in Fig.3.

**[0035]** It can immediately be seen that the good classification results distributed over the diagonal are greatly improved in relation to the previous case, formed by means of a less selective base, less suited to the configuration to which the module is applied.

**[0036]** Adjustment of the database to the conditions of use thus allows, on the one hand, modification of the structure of the network and, on the other hand, to optimize the generalization results obtained.

We claim: